2.3 Panel 3: Utility Integration Issues

2.3.1 Panel Chair:

Charlie Smith – Electrotek Concepts, Inc., Arlington, Virginia

Presentation charts follow

<u>Utility Integration Issues</u>

Hawaii Windpower Workshop
March 21-22, 1994
Honolulu, Hawaii

Prepared by:

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Major Topics to be Addressed

- Shortcomings of Conventional Technology Experienced in Hawaii

- Recent EPRI/HELCO Study on Small System Performance

- Recommendations for the Future

Shortcomings of Conventional Technology Experienced in Hawaii

- Those related to DC Machines with Inverters
  - Poor power factor caused voltage problems
  - Inverters injected large harmonic currents
- Those related to Induction Machines
  - Poor power factor caused voltage problems
  - Wind gusts produce power fluctuations
- Problems were Magnified in Hawaii due to a Weak, Isolated System with Poor Frequency Regulation
  - Voltage regulation problem at Kamaoa
  - Capacitor failures at Kamaoa
  - Harmonic problem at Kealia Substation
  - Frequency regulation problem at Hill 6

the whole Tehachapi area at the same time.

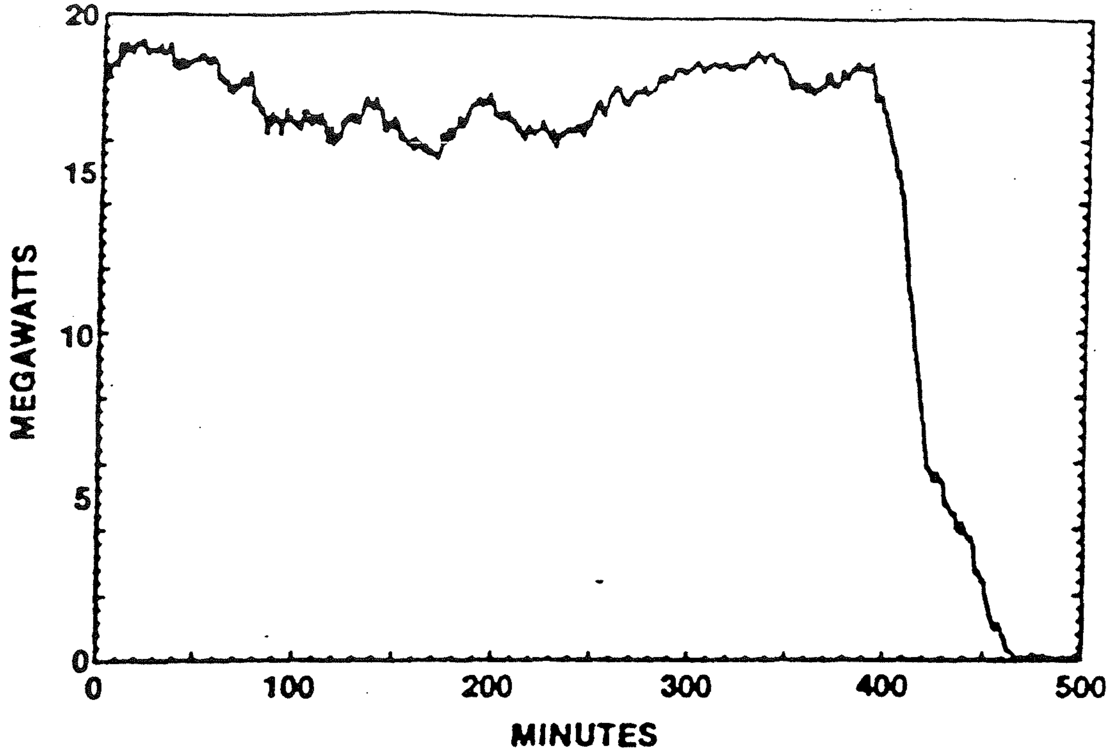


FIGURE 1
LONG PERIOD FLUCTUATIONS

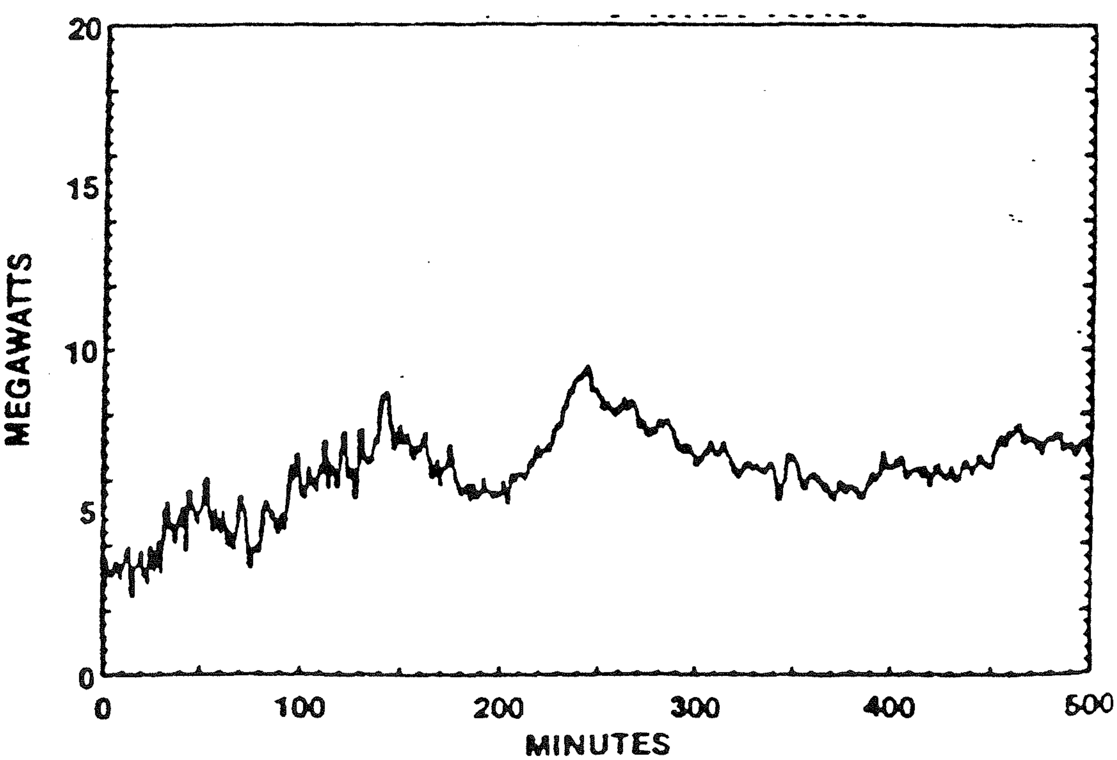


FIGURE 2
SHORT PERIOD FLUCTUATIONS

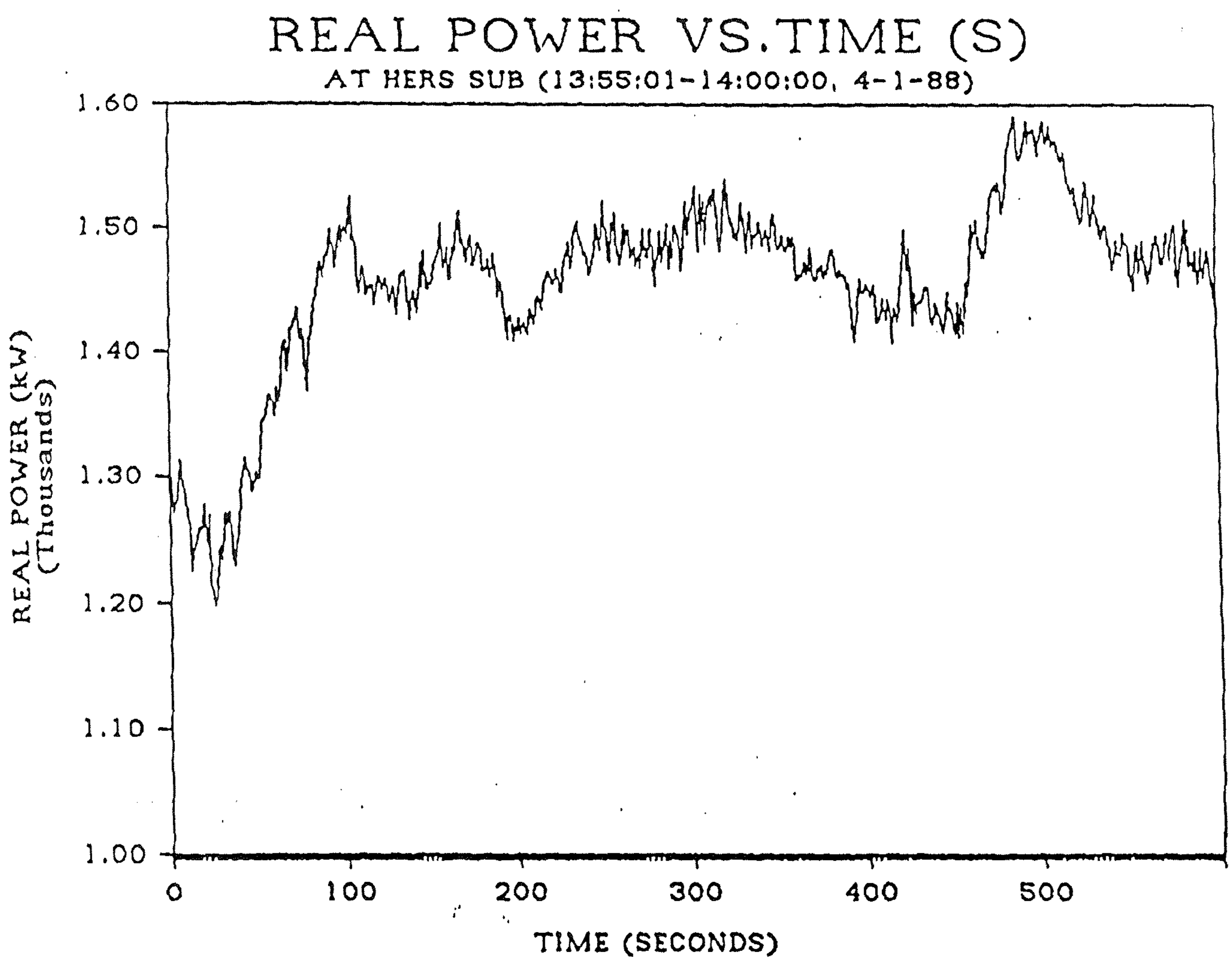


FIGURE 2

Close-up of Real Powers in Second-to-Second Time Frame

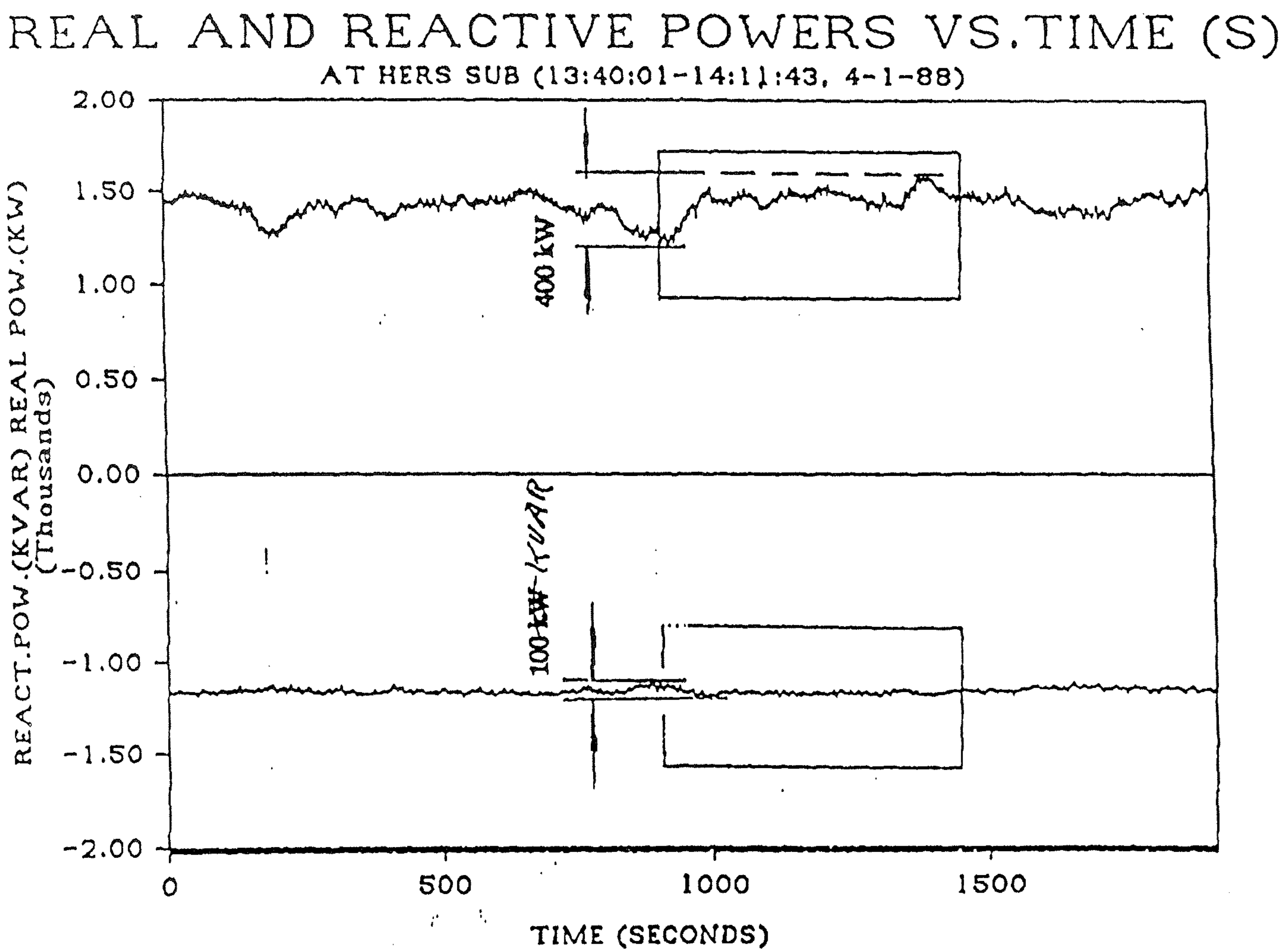
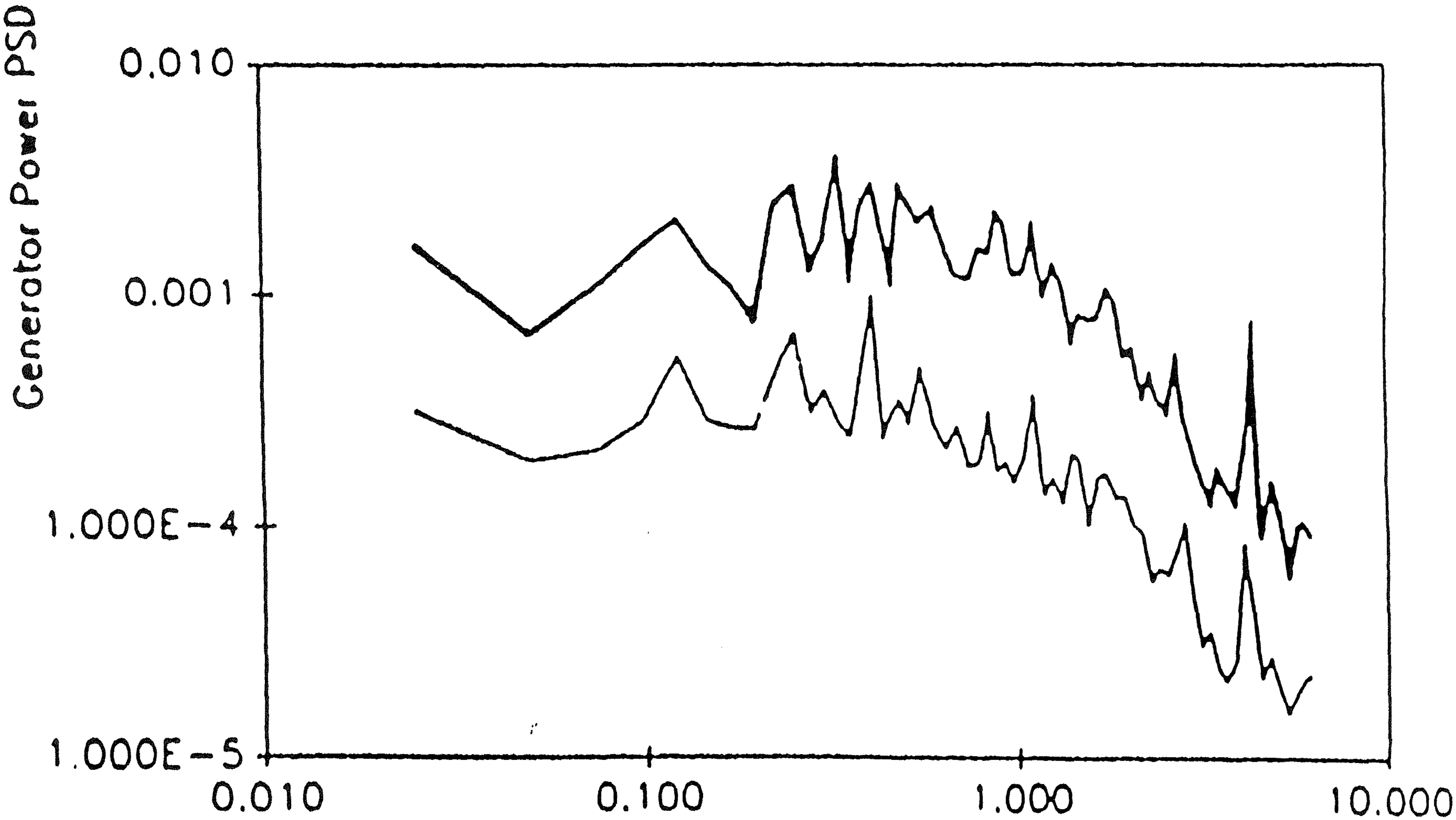


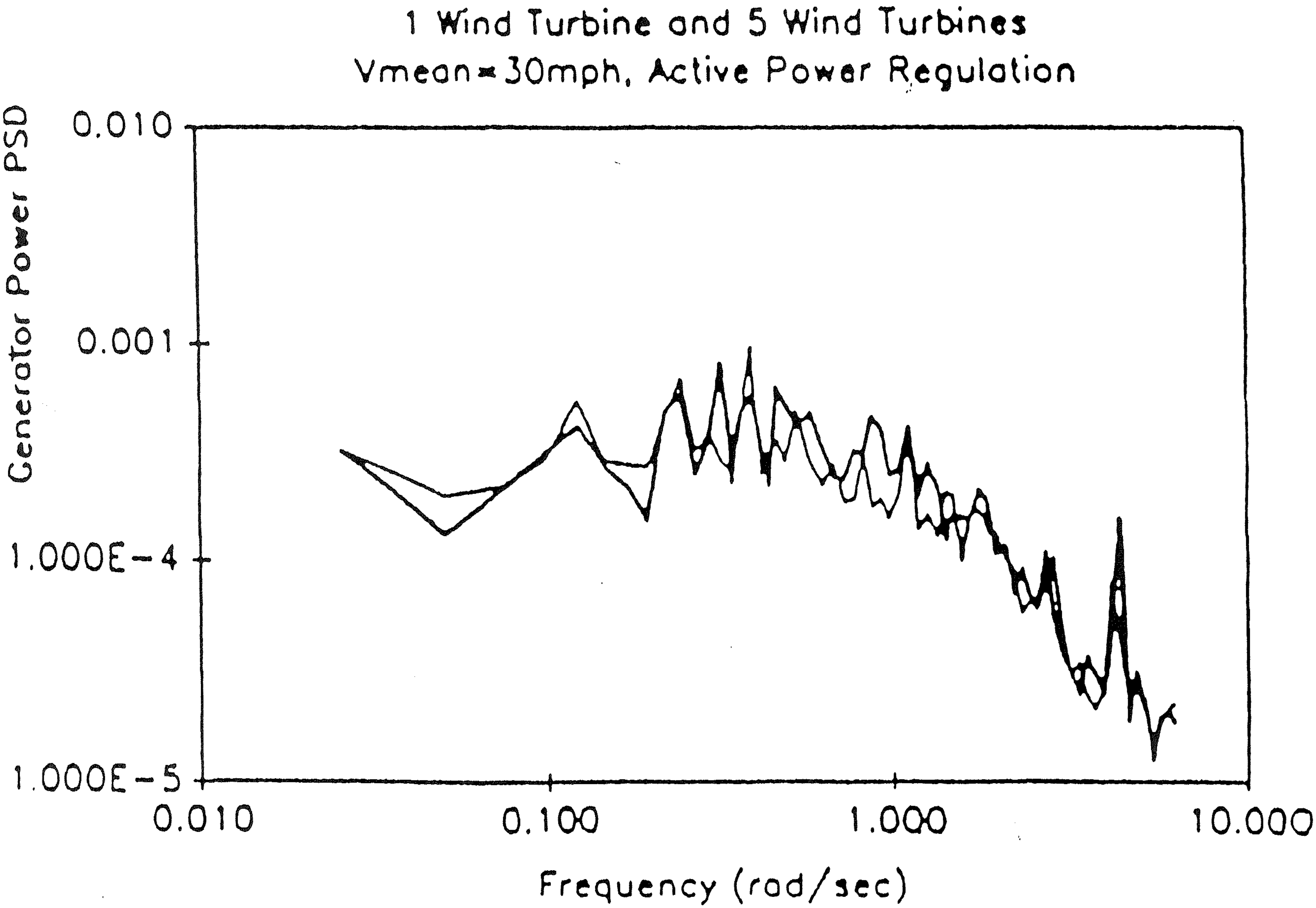
FIGURE 3

Real and Reactive Powers in Secodd-to-Second Time Frame

Normalized Spectra for One Wind Turbine and Five Wind Turbines

Vmean=30mph, Active Power Regulation




1 Wind Turbine and 5 Wind Turbines
Vmean=30mph, Active Power Regulation
Generator Power PSD
0.010
0.001
1.000E-4
1.000E-5
0.010
0.100
1.000
10.000
Frequency (rad/sec)

Hawaii Small System Performance Study

- Study Sponsored by EPRI and HELCO
- Scenario Analysis Approach
- Six Scenarios Identified (1991-1994)
- Study Initiated by PTI Assuming Conventional Wind Turbine Technology
- Study Completed by Electrotek Including Advanced Wind Turbines
- Data for HELCO System Provided by HECO an HELCO
- PTI PSS/E Programs Used for Analysis

Current Situation

- The existing HELCO System Presents a Significant Operating Challenge:
  - Operates isolated
  - Operates without spinning reserve
  - Operates with inadequate regulating capacity
  - Operates with primitive control system
  - Operates with severe transmission constraints
  - Operates with large distance between load and generation

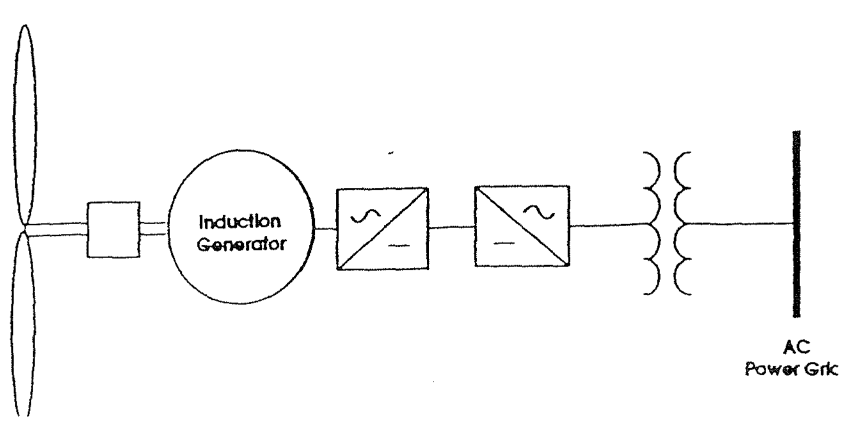
- The Existing HELCO System Experiences Significant Problems:
  - System frequency is difficult to control
  - System voltage is difficult to regulate
  - System reserve margins are low
  - Power outages are a problem
  - Load shedding is increasingly used
  - Rotating blackouts are occasionally necessary

- Conventional Wind Turbines Only Aggravate the Situation

Advanced Wind Turbine Characteristics

- Power Electronic Interface
  - IGBT Power Semiconductors
    - ◊ Increasing capability
    - ◊ Decreasing cost
    - ◊ Can upgrade to MCT
  - High Quality, Low Distortion, Output Waveform
    - ◊ Meets IEEE 519
    - ◊ Requires minimal filtering
  - Provides continuously variable reactive power

- Fast Control Response
  - Constant Output During Gusts
  - Spinning Reserve
  - Participate in System Frequency Control



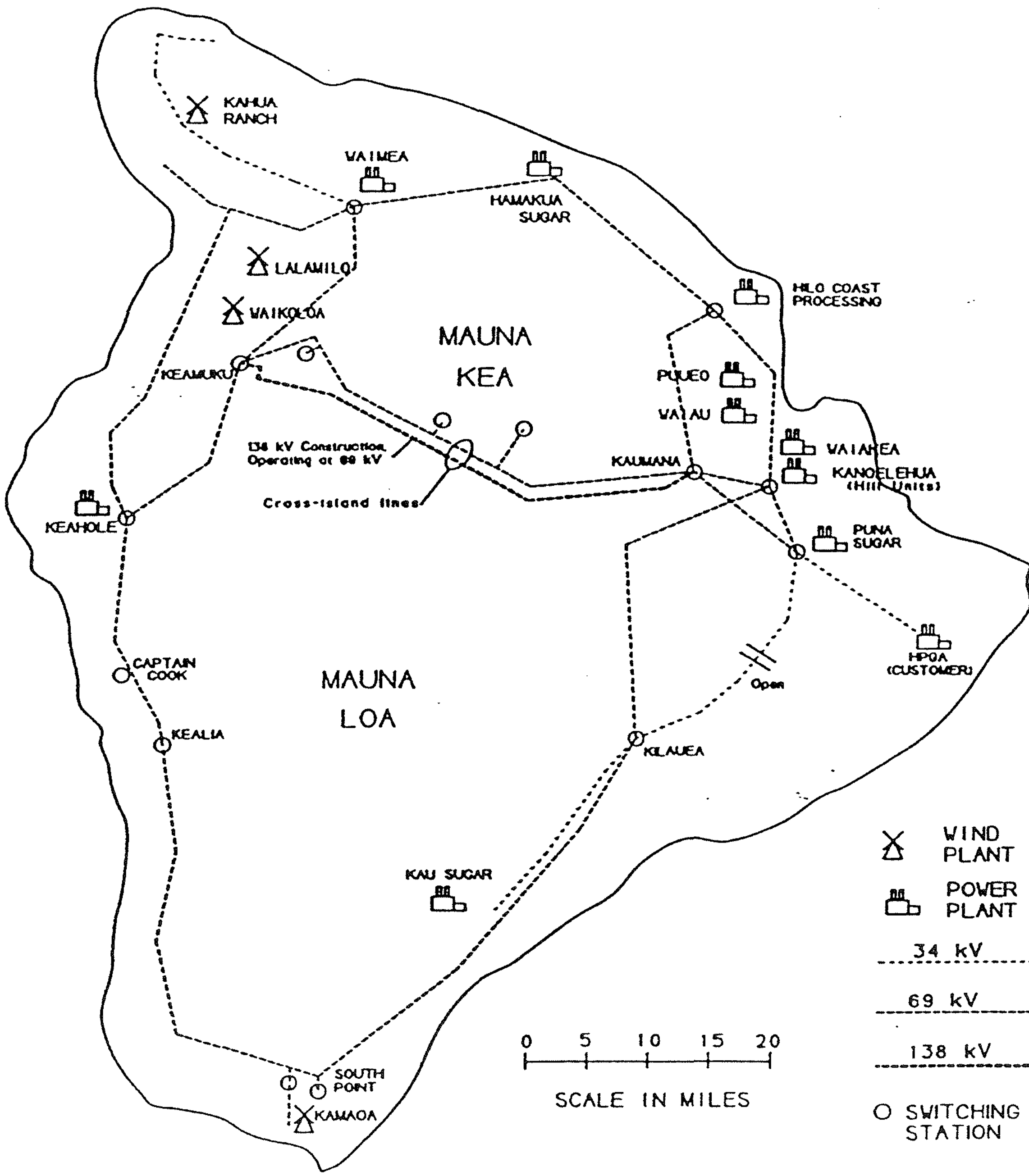


Figure 2-1
HELCO Power System

Power System Scenarios

- A: 1991 Maximum Load, 12.5 MW Conventional Wind Turbines
- B: 1991 Minimum Load, 12.5 MW Conventional Wind Turbines
- C: 1991 Maximum Load, No Wind
- D: 1991 Minimum Load, No Wind
- E: 1994 Maximum Load, 12.5 MW Conventional Wind Turbines,
  21 MW Advanced Wind Turbines
- F: 1994 Minimum Load, 0 Conventional Wind Turbines,
  21 MW Advanced Wind Turbines

Table 2-1: Description of Scenarios: Wind Power Plant Output and HELCO Dispatch
SCENARIOS

	A	B	C	D	E	F
Power System Load, MW	Peak	Minimum	Peak	Minimum	Peak	Minimum
On-Line Units	135	60.0	135.0	60.0	170.5	77.5
Existing WTs, MW	12.5	12.5	0.0	0.0	12.5	0.0
New WTs at Kamaoa, MW					10.0	10.0
New WTs at Waikoloa, MW					11.0	11.0
Hill 6, MW	19.7	11.8	19.4	19.4	20.0	12.0
Hill 5, MW	14.2	14.2	14.2	14.2	14.2	19.5
Shipman, MW	16.4	0.0	16.4	0.0	15.0	0.0
Puna, MW	11.6	0.0	11.6	0.0	13.2	0.0
Combustion Turbine CT2, MW	16.0	0.0	16.0	0.0	13.0	0.0
Combustion Turbine, CT3, MW					19.0	0.0
Geothermal, MW					25.0	25.0
Diesels, MW	15.0	0.0	27.0	0.0	9.0	0.0
Cogenerators, Hydros, MW	33.3	28.7	33.4	35.6	8.6	0.0
TOTAL	138.7	67.2	138.0	69.2	170.5	77.5

Study Objectives

- Examine Impact of Windplants on HELCO System

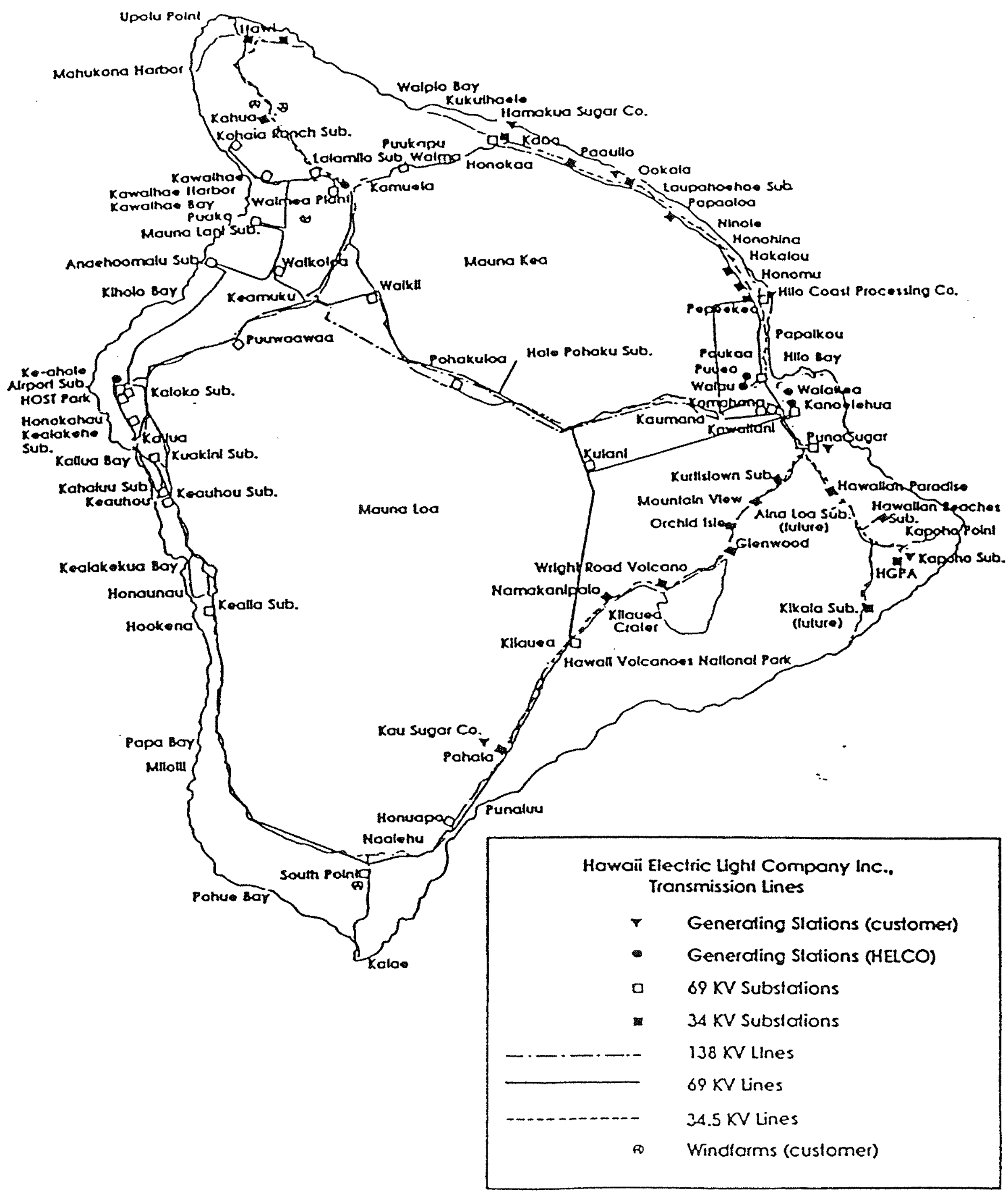
- Examine Alternatives for Controlling Voltage and Frequency Excursions

- Conduct Parametric Investigation to Understand Differences and Probe Limits

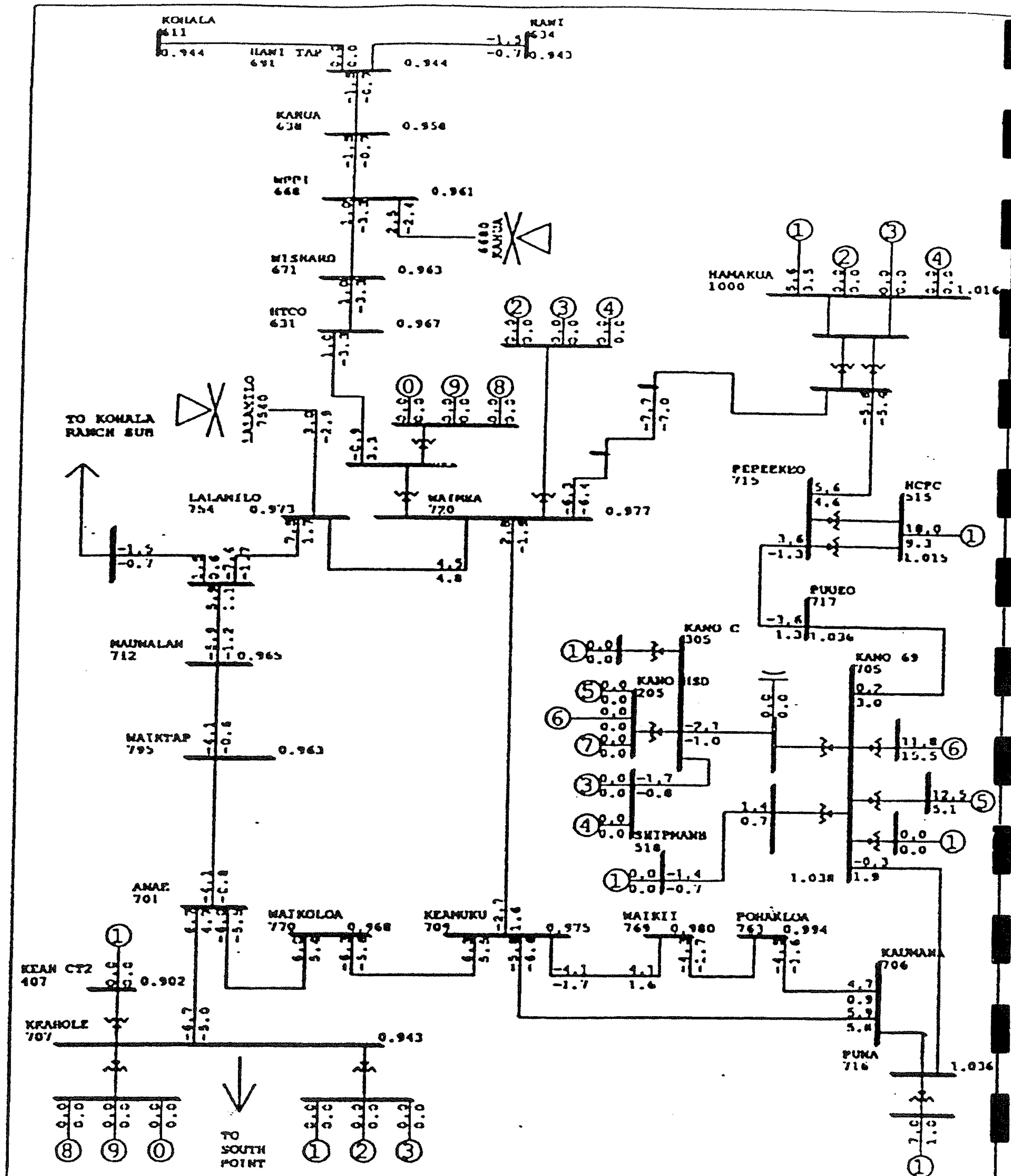
- Include Option of Wind Turbine with Advanced Power Electronic Interface

Reactive Power Considerations

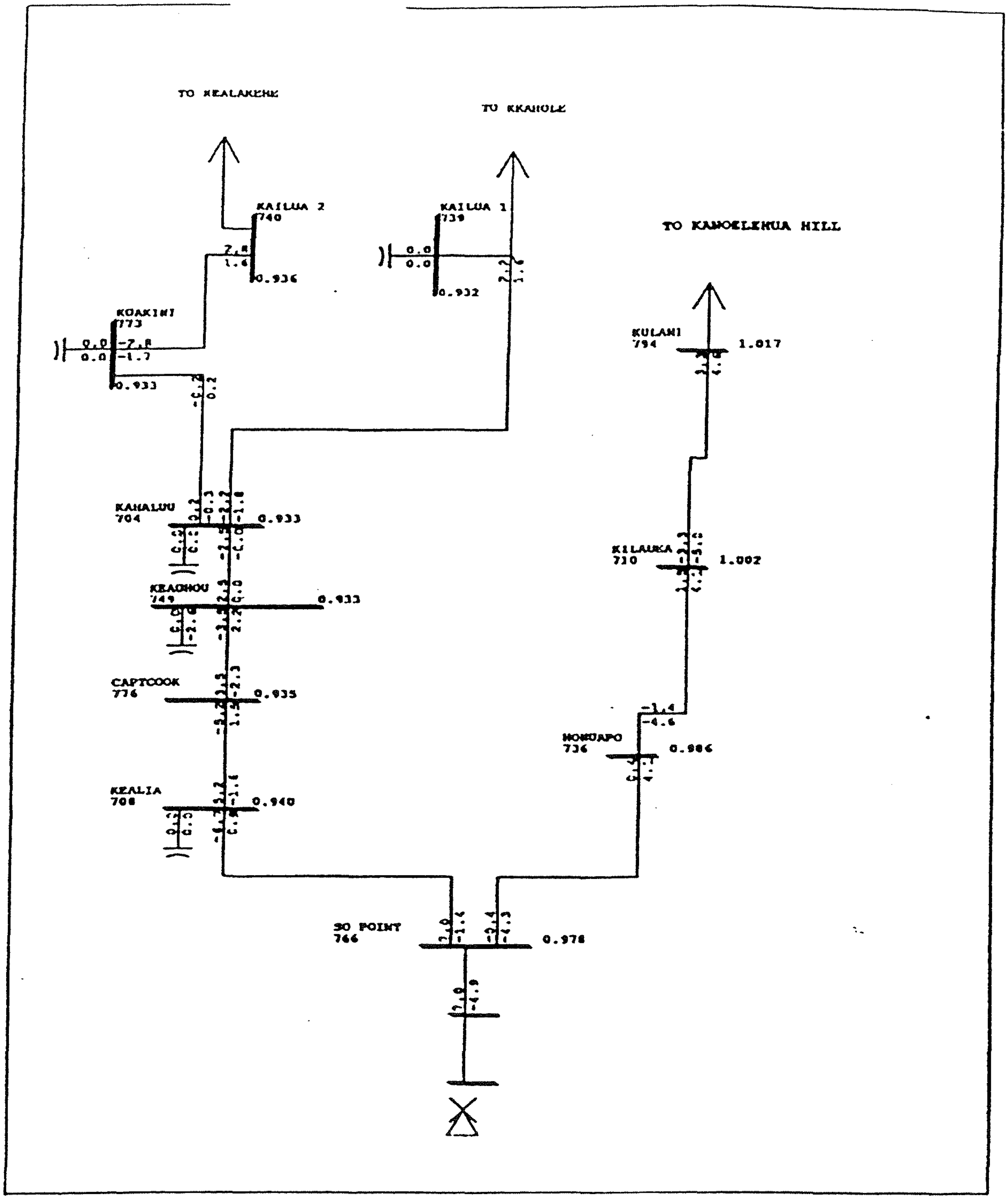
- 1991 System Conditions
  - Assume conventional windplant P.F. is .85
  - Only problem occurs at minimum load with maximum windplant output
  - Significant reactive flow in cross-island tie
  - 10 MVAr capacitor bank required at Captain Cook substation to maintain voltage



HELCO Transmission Line for the Island of Hawaii



Scenario B: Minimum Load with Wind Power Plants at Maximum Power Output



Scenario B: Minimum Load with Wind Power Plants at Maximum Power Output

Reactive Power Considerations

- 1994 System Conditions
  - Compare 21 MW of conventional wind turbines with 21 MW of advanced wind turbines
  - Conventional WTs require 7.5 MVAr more than the base case to meet voltage constraints
  - Advanced WTs require 7.5 MVAr less than the base case to meet voltage constraints
  - Local VAr source reduces system losses
  - 10 MVAr of reactive compensation requirement for convention WTs
- The Bottom Line
  - 25% reduction in system reactive compensation provided by advanced wind turbines

Table 3-1: Scenario E - Power Flow Cases

	Total Generation Output, MW	Capacitors added, MVAr	Output Keahole Combustion Turbine (CT2) MVAr	Total MVAr	System Losses (I^2X) MVAr	Cross-island Line out, System Losses MVAr
Base Case	181.7	46.1	3.5	49.6	35.9	43.0
21 MW -Induction Generator WTs	178.6	49.8	7.3	57.1	30.3	33.8
21 MW -Advanced Wind Turbine	178.3	37.4	4.7	42.1	28.7	32.0

All cases are for a peak load of 170.5 MW, corrected voltages in the transmission system are the same.

Power System Frequency Regulation

- Present Operating Strategy
  - Hill 6 regulates frequency
  - Other units operate with fixed set points with manual controls
  - System operates with no spinning reserve
  - System operates without Automatic Generation Control (AGC) system
  - Hill 6 has limited regulating range due to low fuel pressure trip

Other Operating Strategies

- DEFENSIVE DISPATCH STRATEGY

  – Position Hill 6 to Anticipate Load Changes
    - ◊ Hill 6 low when wind is high
    - ◊ Hill 6 high when wind is low

- MODIFY HILL 6 CONTROL STRATEGY

  – Remove Isochronus Control Below 18 MW Load and Share the Regulating Duty with Other Units

- AGC STRATEGY

  – Put All Units with Governors on AGC

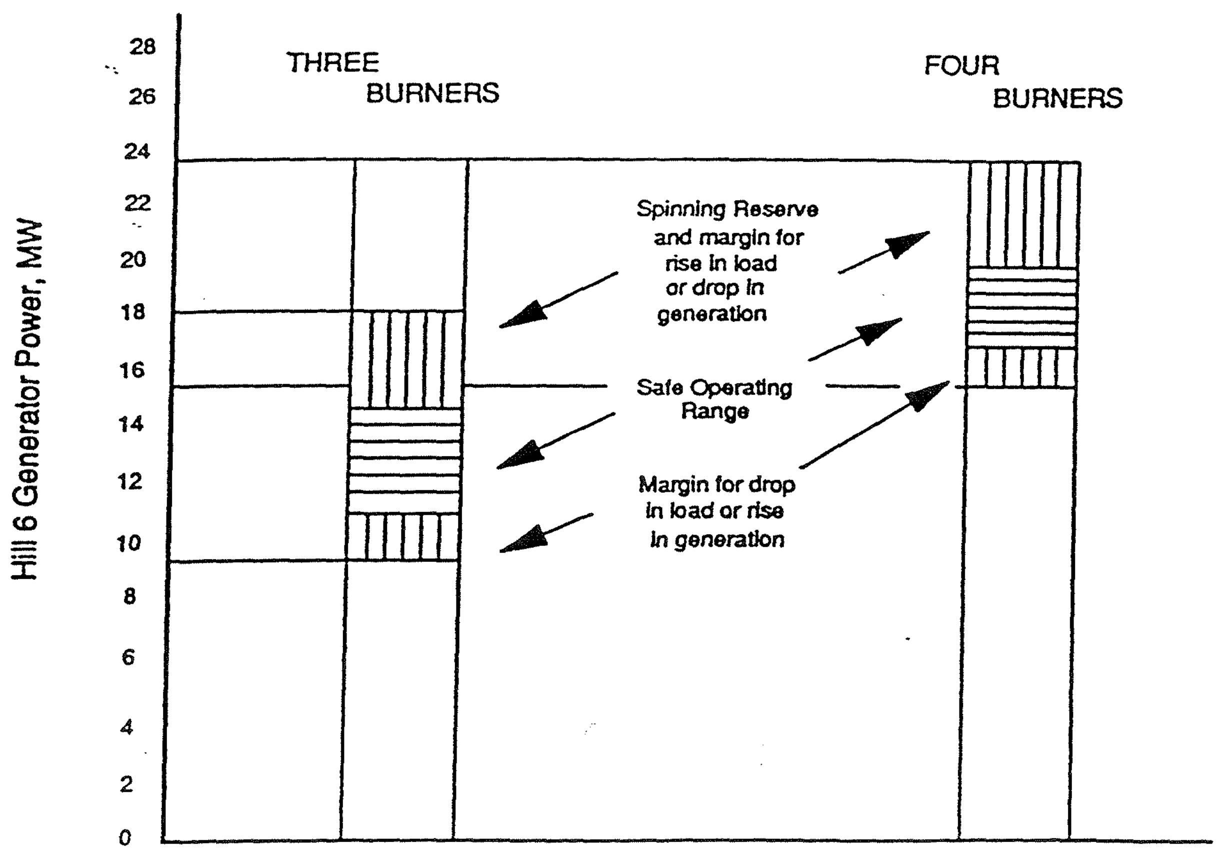


Figure 4-1
Operating Limits For Hill 6
for Three and Four Burners Operating

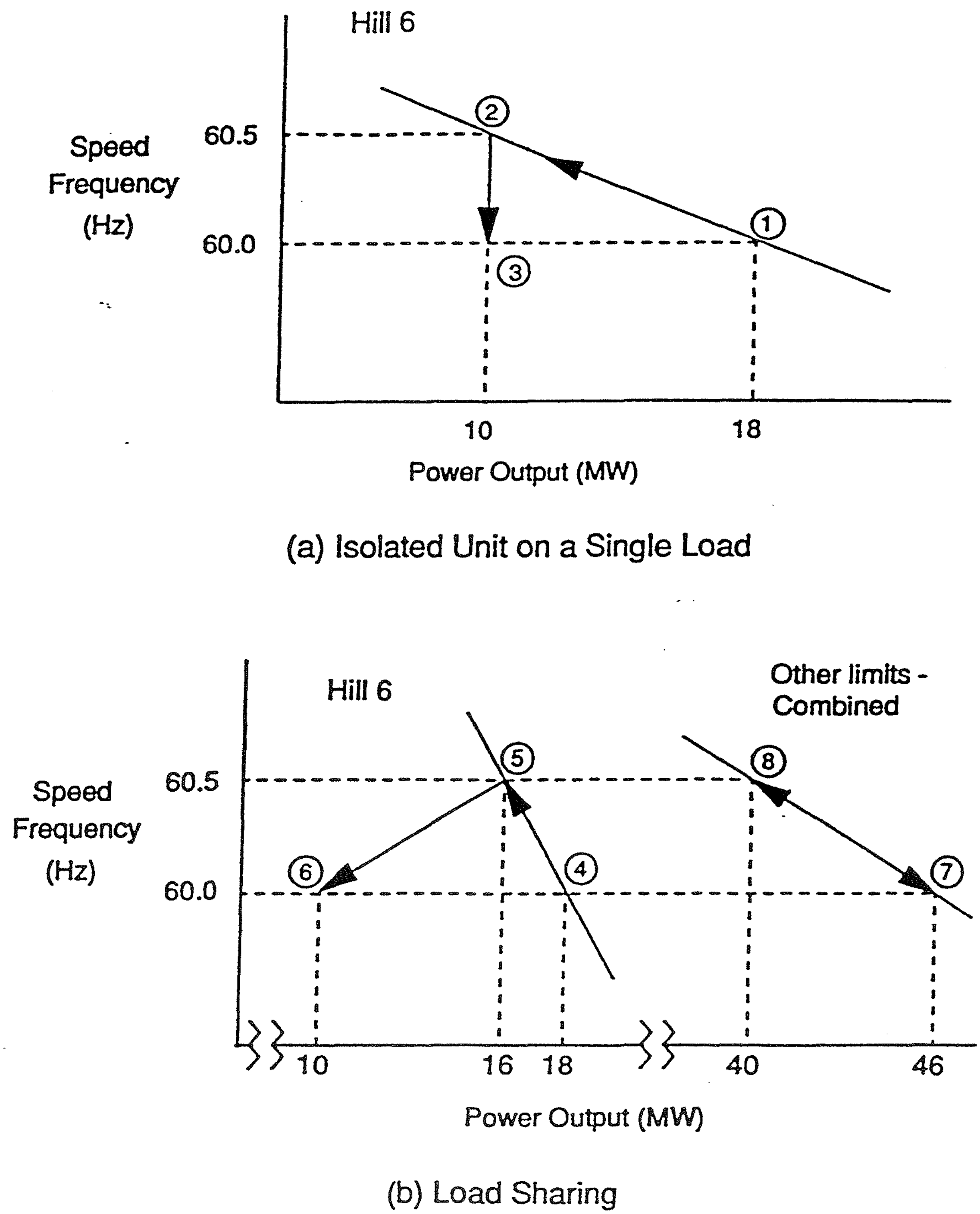


Figure 4-2 Speed Droop Characteristic

Simulation Conditions Examined

- Peak Load
  - Loss of Generation
    - ◊ Hill 6
    - ◊ Kamaoa
    - ◊ Geothermal
  - Wind Gust
    - ◊ 10 MW increase over 1 minute
    - ◊ 10 MW decrease over 1 minute
  - Sinusoidal Variations of Wind
    - ◊ Low *f* variations (5 min) up to 15 MW
    - ◊ High *f* variations (30 sec) up to 5 MW
- Minimum Load
  - Same as above

Table 4-2: Scenario E - Peak Load Case

On-line Units	Scheduled MW	Maximum Power Output MW	Spinning Reserve MW
Existing Wind Power Plants	12.5	12.5	0.0
New Kamaoa WTs	10.0	10.0	0.0
New Waikoloa WTs	11.0	11.0	0.0
Hill 6	20.0	24.0	4.0
Geothermal	25.0	25.0	0.0
Combustion turbine 3, CT3	19	23.6	4.6
Keahole; CT2	13.0	16.0	3.0
Diesels	9.0	9.0	0.0
Other Units[1]	51.0	63.4	12.4
TOTALS	170.5	194.5	24.0

1 Other units include Puna, Shipman, HCPC, Hamakua, Hill 5 and the hydro units.

Table 4-4: Scenario F - Minimum Load Case

On-Line Units	Scheduled MW	Maximum Power Output MW	Spinning Reserve MW
New Kamaoa WTs	10.0	10.0	0.0
New Waikoloa WTs	11.0	11.0	0.0
Hill 6	12.0	14.0	2.0
Hill 5[1]	19.5	33.7	14.2
Geothermal	25.0	25.0	0
TOTALS	77.5	93.7	16.2

1 Hill 5 is a combination of Hill 5, HCPC, and Hamakua.

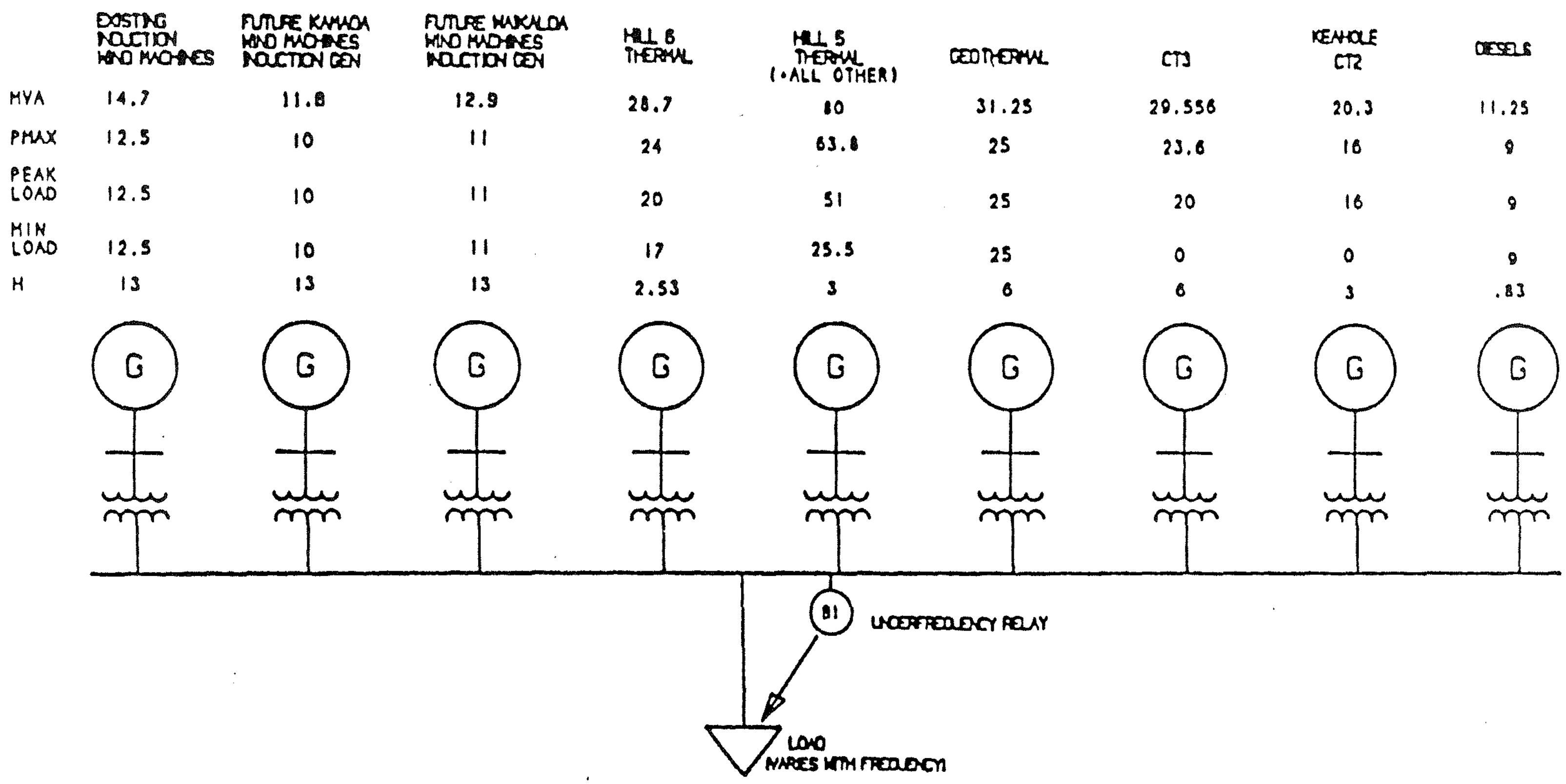


Figure C-1 Ten Bus Simulation Model
(see attached generator and governor parameters)

Major Observations

- Loss of Generation
  - Sufficient spinning reserve is available during peak load periods to cover the loss of the largest unit.
  - Wind turbines help arrest frequency decline.
  - Insufficient spinning reserve during minimum load conditions results in frequency decline >.7Hz and load shedding during the loss of the largest unit.
  - This is the limiting case and wind turbines are not a factor.
  - An alternative operating strategy with advanced wind turbines could help the situation, i.e. provide spinning reserve.

Major Observations

- Ramping and Sinusoidal Variations of Wind Generation
  - Decrease of 10 MW in 1 minute is not a problem in either the maximum or minimum load case, given the spinning reserve.
  - Increase of 10 MW in 1 minute creates problems with low load on Hill 6.
    - ◊ Present and defensive dispatch strategies cannot prevent Hill 6 trip during peak load or minimum load conditions.
    - ◊ Speed-droop control and AGC eliminate problems for maximum load condition, but cannot prevent Hill 6 tripping during minimum load conditions
    - ◊ Advanced wind turbines solve the problem by limiting turbine output during increasing wind conditions.

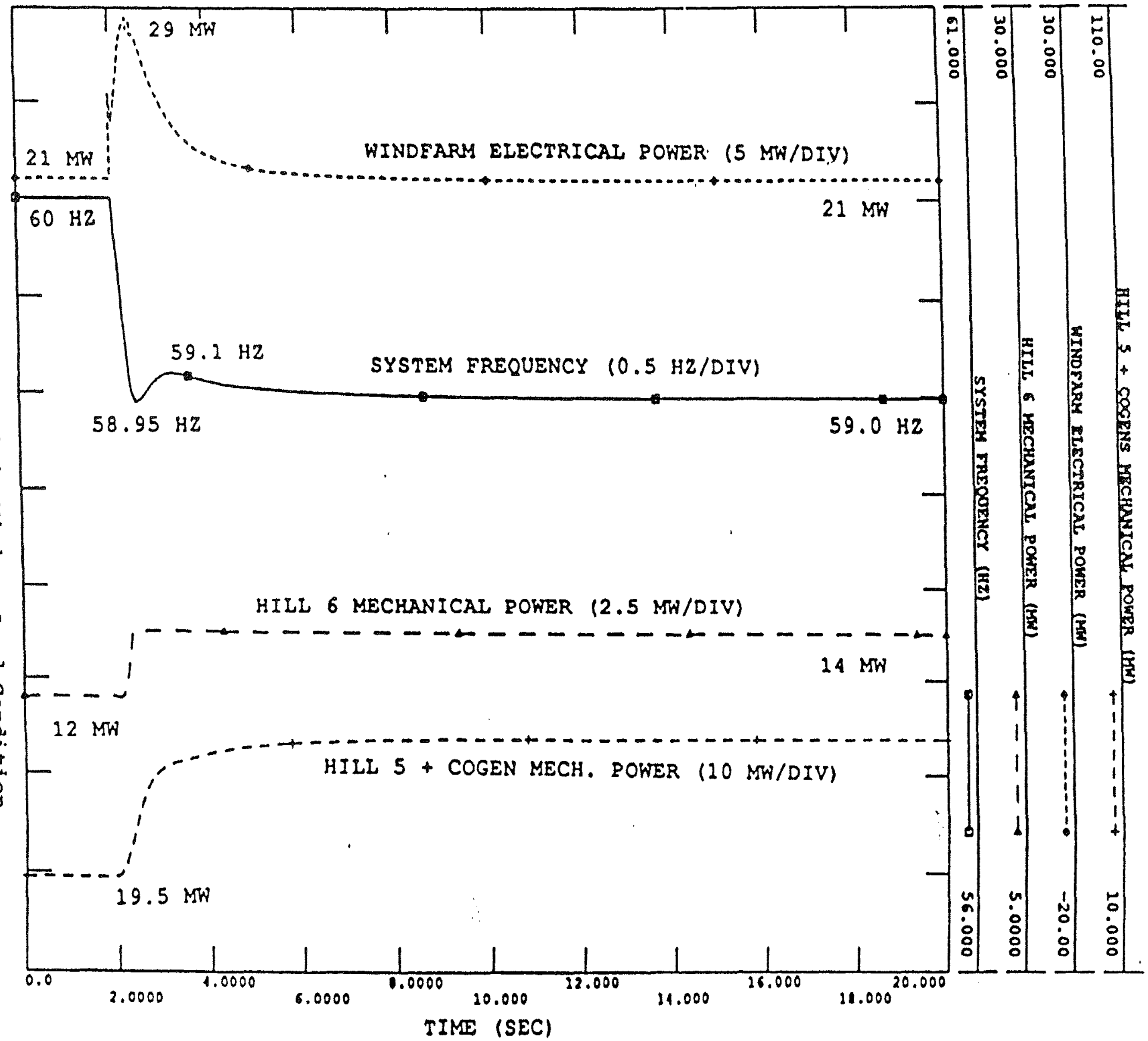
Table 4-5: Summary of Simulation Results with Conventional Wind Turbine Technology

Frequency Regulation	System Load	Loss of Generation	Ramp Up WTs 10 MW, 1 min.	Ramp Down WTs 10 MW, 1 min	Sinusoidal WT Output Variations
Present Dispatch Method	Peak Load	Frequency excursion	Hill 6 tripped+	Hill 6 to maximum output	Hill 6 tripped+
	Minimum Load	Frequency excursion, Load shedding	Hill 6 tripped+	Hill 6 to maximum output	Hill 6 tripped*+
Defensive Dispatch Method	Peak Load	Same as Present Dispatch Method*	Hill 6 tripped+	Hill 6 to maximum output	Hill 6 tripped*+
	Minimum Load	Same as Present Dispatch Method	Hill 6 tripped+	Hill 6 to maximum output*	Hill 6 tripped*+
Isochronous to Droop-Speed Control	Peak Load	Same as Present Dispatch Method* 1	Hill 6 backs down to minimum output	Hill 6 to maximum output*	Hill 6 backs down to minimum output
	Minimum Load	Same as Present Dispatch Method* 1	Hill 6 tripped+	Hill 6 to maximum output*	Hill 6 tripped*+
Automatic Generation Control	Peak Load	Same as Present Dispatch method* 1	Hill 6 backs down with other units*	Frequency excursion, restored to 60 Hz	Hill 6 backs down with other units*
	Minimum Load	Same as Present Dispatch Method* 1	Hill 6 tripped*+	Frequency excursion, restored to 60 Hz	Hill 6 tripped*+

1 These frequency regulation methods do not influence the amount of spinning reserve.

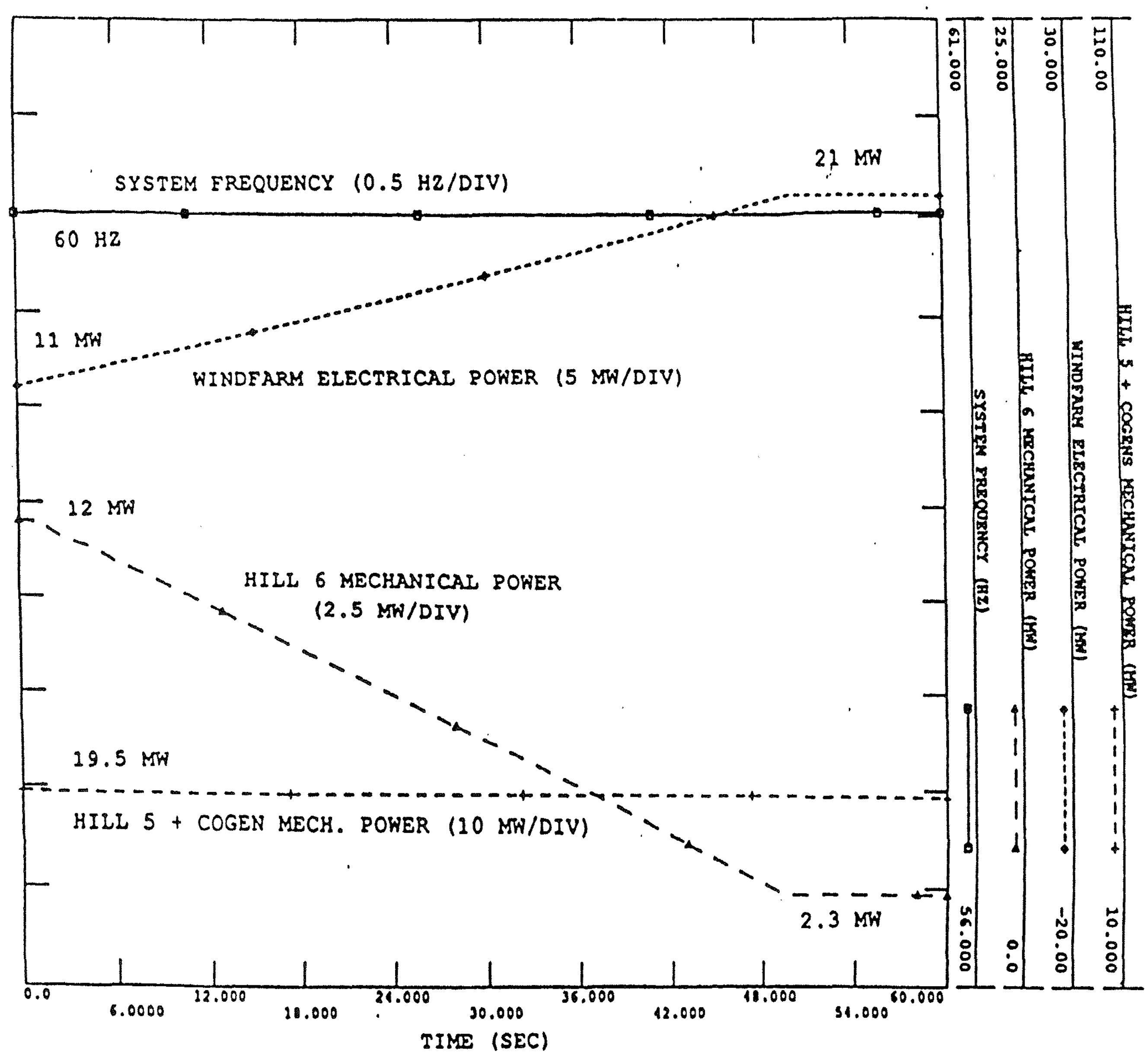
* Result was derived from other actual simulations

\+ Result can be avoided with advanced wind turbine technology



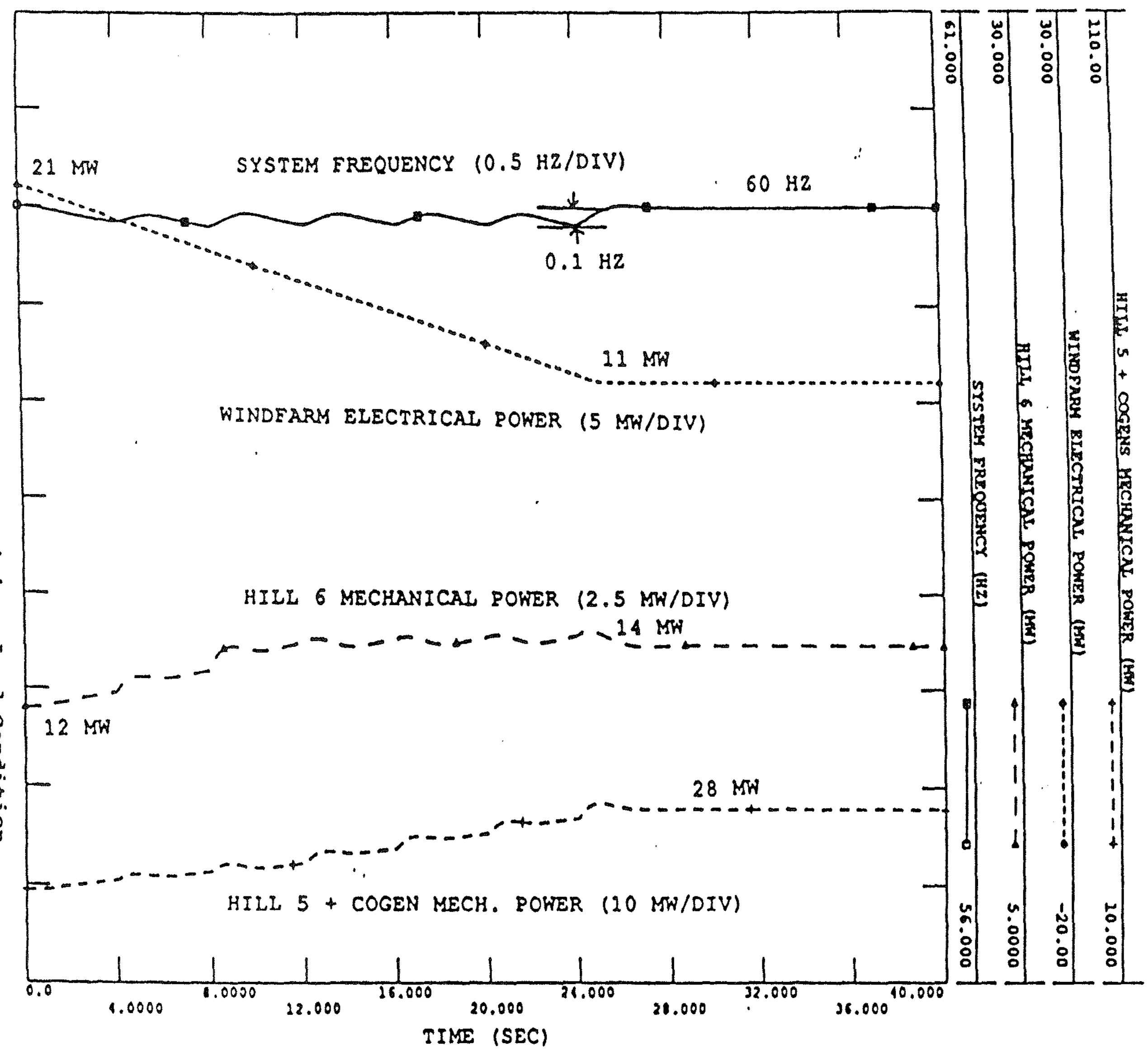
Case S14: Present Dispatch Method, Loss of Geothermal Plant

Scenario F: 1993-4, Minimum Load Condition



Scenario F: 1993-4, Minimum Load Condition

Case 16: Present Dispatch Method,
Wind Power plants Ramp Up



Scenario F: 1993-4, Minimum Load Condition

Case S20: Automatic Generation Control,
Wind Power Plants Ramp Down

Final Conclusions

- From a system dynamics point of view, to a first approximation, the limiting factor for the size of the largest wind plant employing advanced wind turbine technology is the size of the largest conventional unit.

- Advanced wind turbines, either in isolation or as part of an AGC strategy with spinning reserve, offer the opportunity for increased amounts of wind generation and improved system operation.

RECOMMENDATIONS FOR THE FUTURE

- Adopt a spinning reserve policy
- Implement an AGC system
- Evaluate advanced wind turbines for any future installations
- Look at benefits of energy storage, with or without renewables
  - Batteries for short-term (1-3 hours) storage and system operating benefits
  - Pumped hydro for long-term (5-20 hours) storage and system reliability benefits
- Look at combined pumped hydro-water use project taking water from Hilo to Kona

Quit talking about wind penetration and start looking at power system planning, operating, and reliability issues.

2.3.2 Panel Members:

Hamish Wong–Hawaiian Electric Company (HECO)
Ed DeMeo–Electric Power Research Institute (EPRI)
Jonathan Lynch–Northern Power Systems (NPS)

Panel Responses

Ed DeMeo – Electric Power Research Institute (EPRI)

Mr. DeMeo took time to discuss the utility groups that have formed to support the realization of wind as a viable technology. Two of the principle organizations he discussed were the Utility Wind Interest Group and the Wind Users Support Group. An important role was played by members of the Hawaii utilities during the formative stages of these groups, Mr. DeMeo noted.

The Utility Wind Interest Group - formed in 1989, this group is comprised of 13 utility company members together with support from NREL, U.S. DOE and EPRI. The group functions by investigating current developments in the technology and communicating that understanding to the utility industry as well as other interested parties.

Wind Users Support Group - more recently formed, this group deals more with the *nitty-gritty* issues of how to integrate wind into the utility system. Currently, 25 utilities are active members and have formed a group of cost-shared projects each dealing with specific areas. Results from these projects are expected to offer insights into such issues as prediction capability, resource availability and other technical issues.

In addition, the group is supported by organizations from the wind community, such as R. Lynette & Associates, providing valuable input to utilities interested in getting started in developing wind and initiating the process properly.

An experience base the wind technology is developing within the utility sector, Mr. DeMeo said, and he encouraged the Hawaiian Islands to participate in these groups not only to gain knowledge from others but also to bring their own unique experiences to the group.

Hawaii has been a very good laboratory in areas such as the high penetration of wind and its impact on the utility system, he said.

In addition, these groups are currently experiencing a major expansion and, over time, will have an impact on the technology as it evolves, he said in closing.

[NOTE: Ed DeMeo's presentation charts follow this page.]

Utility Wind Interest Group (UWIG)

Formed by utilities mid 1989 with DOE and EPRI support

Current membership: 13 utilities

Mission: Expedite appropriate integration of wind power for utility applications

Strategy: Understand and communicate status and issues
- experience exchange
- wind industry interactions
- brochures and seminars

Six brochures published; several in process

EPRI Wind Users Support Group

- Formed by EPRI in 1993 with DOE/NREL cooperation
- Identify and address key integration issues
- Cost-shared projects
- In-depth experience exchange
- Initial membership: 22 utilities

Wind Users Support Group

<u>Initial Projects List</u>

1. Wind Energy for Utilities Primer
2. Wind Resource Planning Frameworks
3. Regional Reliability Council Accreditation
4. Short-term Hourly Energy Forecasts Methodologies
5. Interannual Variability Assessment Methodologies
6. Environmental Issues (Avian, Visual, Noise,etc.)
7. Electrical Interconnection Description

Hamish Wong – Hawaiian Electric Company (HECO)

February was a good for month for wind generation, according to Mr. Wong, with 6 -7 MW of wind power generated during peak hours at some wind sites and 2-3 MW generated during low times.

The intermittency of wind generation in Hawaii is such that you are faced with it from hour to hour. That kind of wide variation and the impact of how it appears on the customer's side remains to be seen, Mr. Wong said in referencing Charlie Smith's recommendation for utility system planning. This issue in Hawaii needs more careful study before we can conclude that the size of the wind farm should be limited to the size of the largest conventional unit available, he said.

With regards to evaluating 21 MW of advanced wind turbines mentioned in Mr. Smith's presentation, Mr. Wong stated that whether or not HECO can step up to the wind power capacity of 21 MW remains to be seen. Presently, HELCO uses turbines with 12 MW wind capacity for power generation on the Big Island and these turbines present system problems, he said acknowledging the fact that these units are conventional turbines.

As for installing an automatic generation control (AGC) system to help the system accept more power generation, Mr. Wong noted that HELCO is considering installing one on the Big Island in a couple of years.

In closing, Mr. Wong affirmed his belief in the an energy system as a promising concept for minimizing the impact of intermittent power variations on an operating system.

Jonathan Lynch – Northern Power Systems (NPS)

Speaking from the perspective of Northern Power Systems, a manufacturer of wind turbines and its parent company, New World Power, a developer of overall projects, Mr. Lynch said he viewed the work by EPRI and Electrotek to be extremely important and valuable in designing systems for wind power.

Whether or not it wanted to be, Hawaii is a pioneer in utility scale systems for wind turbines on soft grids, he said noting that his organization did not run into the same problems in developing systems at the same level on the mainland.

Presently Northern Power Systems and New World Power are bridging from isolated village systems of up to 50 -100 kW through small MW wind systems and up to fully integrated utility grid systems.

NPS is dealing with the same issues and the same analyses as EPRI and Electrotek in addition to the simulation programs going on now to work with these issues. Advanced wind turbines, separate from overall system analyses, offer frequency control and easily dispatchable power ratings with the ability to control the overall power level of the wind farm.

He added that Northern Power Systems is starting to add storage to its smaller systems (50 - 200 kW). For one to two hours of storage in a 50 to 100 kW size system, 100% wind penetration was obtained and frequency was held within ½ of a hertz with a fluctuating load level. When the economics and the technology improves, particularly as pump hydro storage becomes available, these full featured models may be available for larger systems.

In closing, he noted that the key lesson learned by the industry has been that wind turbines cannot be installed in isolation. The overall system must be considered. Molokai represents an interesting site because it is an island where a lot of ideas being perfected in other places can be applied. Due to its smaller scale size, solutions are easier.

Question:

Given that there are a number of modifications that could be made to improve the operation of the grid, which of these are benefits primarily for wind and which are beneficial for system operation?

Answer:

Charlie Smith –Electrotek Concepts

AGC system is the largest single item that would cause the improvement of the system's operation with or without wind.

Hamish Wong –Hawaiian Electric Co.

Solutions are primarily a function of the characteristic of the power source. There are various solutions to problems depending on the source of power and the solutions for one power source (i.e. photovoltaics) may not work for another (i.e. wind). Unfortunately, we are not at the point yet in Hawaii where we can modulize the system and handle each power source individually.

Charlie Smith – Electrotek

It is important to keep in mind that solutions to frequency control, spinning reserve and other problems cost money to implement and we are dealing with a situation where upgrading the system by implementing these solutions represents an investment that has to be measured against the rate impact to the power consumers. The ultimate question is, what is the rate impact pain level of the rate payers?

Question:

What about the addition of another 25 MW geothermal unit. What would the impact be on the spinning reserve with the loss of an additional 25 MW geothermal unit?

Answer:

Charlie Smith – Electrotek

If the units are independent and connected to different generators, step-up transformers and different buses, then the probability of any single event affecting both units is pretty small. If you can treat them as independent events, then the loss of the largest unit is still only 25 MW, or maybe only 12 MW, depending on how the existing system is connected, e.g. if both units are electrically and mechanically separate.

But if you look at the spinning reserve impact and you have a minimum load of 60 MW, you will have to pay a heavy penalty for that loss because of the need to keep enough units on-line operating at minimum load to be able to provide spinning reserve to cover the loss of the largest unit.

Question:

What would the impact have been if the power factor on conventional power systems started off at 95% versus 85% ? Is the 10 MW ramp rate criteria too severe?

Answer:

Charlie Smith – Electrotek

In response to the first question, the impact is that it just would not have required as much to keep the voltage within the bounds of capacitance. The range of voltage was 95% to 105% capacitance and we only added capacitors if the voltage range went out of the + or- 5% bounds. Instead of a situation where there is a 15 Mvar requirement being compared to the conventional turbines, you might have had a 7 Mvar requirement. Clearly, it would have reduced the Mvar requirement.

As to the severity in the assumption of the 10 MW ramp rate, the criteria is an extremely conservative design criteria, Mr. Smith said, based on wind data he has seen at other wind sites.

"By that I mean you don't normally expect 80% output changes over a one minute time span. The Tehachapi data is more typical but I don't have any similar wind data for Hawaii. I don't know what kind of variations you get or can expect here," he said emphasizing that it is a pretty stiff design criteria to meet.

Question:

What were the assumptions made about the 10 MW change from the wind turbines happening across the islands of Hawaii?

Answer:

Charlie Smith – Electrotek

It was just a MW change and no assumptions were made about what sites it was coming from. It was assumed that the advanced wind turbines were lumped together and it was assumed there was a 10 MW change from the wind turbines and we didn't look at any permanent spatial diversity. It was assumed that there was a 10 MW permanent change. However, if you experience the change simultaneously across the islands then you obviously lose that diversity factor and can no longer have a number of 10 MW wind plants. Instead, it starts to look like one 20 to 30 MW wind plant.

Question:

What criteria did you base your assumption on, that a wind farm should be limited by the size of the largest conventional unit on the island?

Answer:

Charlie Smith – Electrotek

The assumption was made using the normal standard planning criteria for power systems on the mainland. You should maintain sufficient spinning reserve and operating reserve to tolerate the loss of your largest unit on that system and maintain its operational integrity.

Hamish Wong – Hawaiian Electric Company

The situation in Hawaii is different, Mr. Wong said offering as a comparison, systems in Europe and on the west coast of the U.S. where 1000 MW is just a fraction of a percent of the available capacity. It may be an uncomfortable situation there but it is manageable.

However that situation is a little different in Hawaii where the existing amount of wind capacity is already 8% to 10% during peak load periods and is probably even higher than that during low load periods. Therefore, a loss of a large block of power in a short period of time would be very hard to handle from an operating perspective, he said.